A 1.75 GHz Waveguide Schottky Detector for the Recycler

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Abstract: *A 1.75 GHz waveguide schottky detector has been designed and built for the Fermilab Recycler ring. The waveguide detector is designed to measure the betatron sideband signals of the machines. Two detectors are used in the machine; one for horizontal betatron signals, and one for vertical betatron signals. This paper describes the details of the electronic system of the detector. The electronic system converts the 1.75 GHz signals to frequencies less than 10 MHz, so that the signals may be analyzed by a vector signal analyzer. The electronic system includes electronic gates to measure single or multiple bunches of protons or antiprotons, and the electronic system also includes a monitor to measure the real time emittance of the machine. A simplified block diagram of the entire system is shown in fig. 1.*

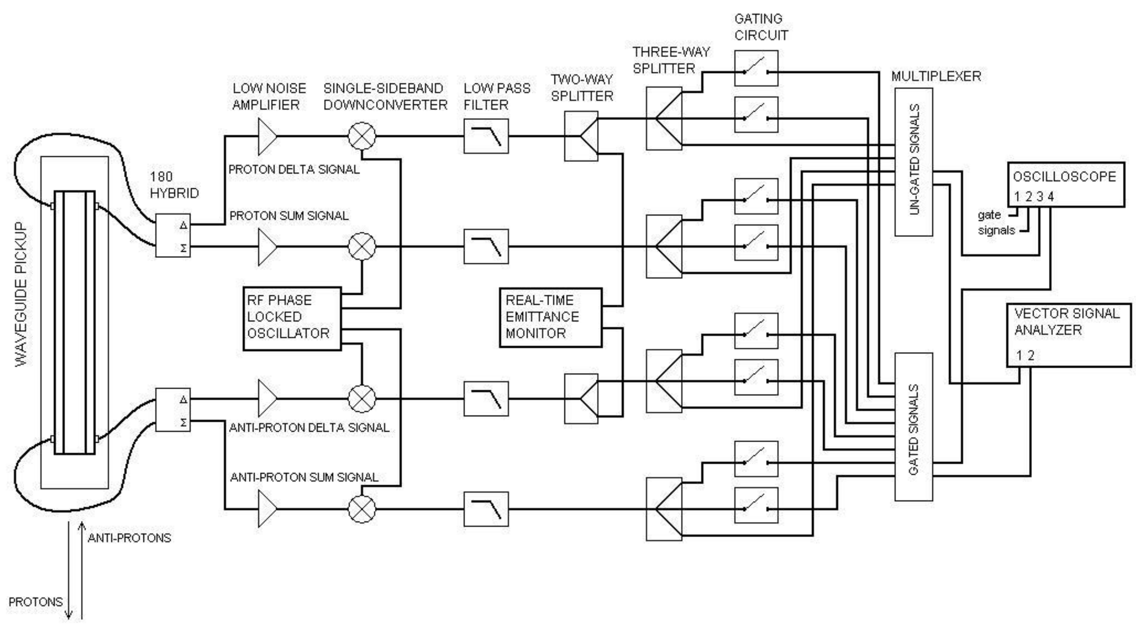


Fig. 1. Simplified block diagram of the Recycler 1.75 GHz Schottky detector system

Waveguide Pickup

The waveguide pickup is a high impedance, narrow bandwidth pickup. There are two pickup tanks in the recycler; one for horizontal signals, and one for vertical signals. A diagram of the waveguide structure is shown in fig. 2. The proton, or anti-proton, beam couples to the waveguide through slots, and the structure has a directivity of about 10 dB. A 180 hybrid is connected to the outputs of the waveguide as shown in the block diagram in fig. 1. The hybrid allows the waveguide to measure sum and difference (delta) components of the beam. The sum and delta modes have a slightly different center frequency. The calculated delta and sum mode have center frequencies of 1.745 GHz, and 1.813 GHz, respectively. The bandwidth of both modes is approximately 100 MHz. A plot of the calculated data is shown in fig. 3. The measured data shows a shift downward in the center frequency of about 40 MHz. Details of the waveguide design and measurement are shown in [1], [2] and [3]. The waveguide pickup tanks are located in the MI-62 section of the recycler, and the mechanical drawing of the horizontal and vertical tanks are ME-326574, and ME-326569.

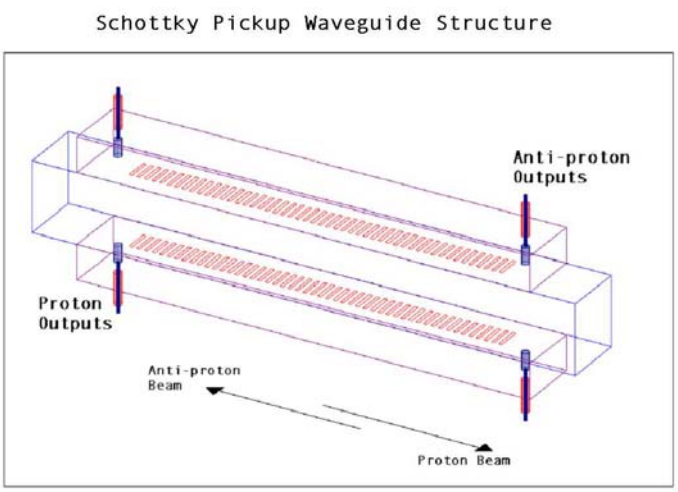


Fig. 2. Waveguide structure

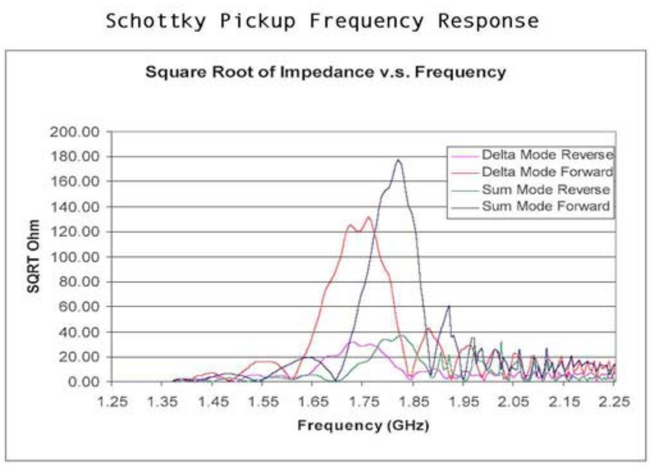


Fig. 3. Calculated frequency response of the sum and delta modes of the pickup

MI-62 Tunnel Electronics

Details of the tunnel electronics are shown in fig. 4. It is desired to have the best possible signal to noise ratio for the system, so the choice and construction of the electronics at the front end of the system is important. The amount of noise added to the system by the electronics is given by the noise figure F, and is defined as,

$$F = F1 + (F2-1)/G1 + (F3-1)/(G1*G2) + (F4-1)/(G1*G2*G3) + \dots \qquad (1)$$

Where Fn and Gn is the noise figure and gain of the individual components, respectively. The signal to noise at the output of the system is given by,

$$So/No = (Si/Ni) / F \qquad (2)$$

From eq. 1, it is seen that it is desired to have high gain and low noise figure for the first few electronic components. Miteq AFD3-010020-12-LN low noise amplifiers are chosen to amplify the signals at the front end of the system. These amplifiers have a noise figure of 1.2 dB and a gain of 42 dB. The amplifiers are placed in the tunnel as close as possible to the signal outputs of the waveguide pickups. Some passive components are needed before the signals can be amplified, as seen in fig. 4. The losses of the passive components placed in front of the amplifiers will add noise to the system, so care must be taken to keep these losses to minimum. For example, the cable lengths should be as short as possible between components. The components before the low noise amplifiers include a 180 hybrid, a 20 dB coupler, and a high pass filter. The hybrid is for generating the sum and delta signals, the 20 dB coupler is used to inject a test signal into the system, and the high pass filter is used to eliminate the strong low frequency components that might damage the low noise amplifiers. The total loss of the passive components listed above is approximately 1.8 dB. The variables of eq. 1 become

$F1 = 1.8$ dB $= 10 \wedge (1.8/10) = 1.51$ (increases with temperature)

$G1 = 1 / 1.51$

$F2 = 1.2$ dB $= 1.32$

$G2 = 42$ dB $= 15848$

$F3 = 5$ dB $= 3.16$

For completeness, the noise figure of the ½ heliax cable after the low noise amplifiers is included as F3. The total noise figure is,

$$F = 1.51 + 1.51 * (1.32 - 1) + 1.51 * (3.16 - 1) / 15848 + \dots$$

$$F = 1.99 = 3.0 \text{ dB}$$

It is seen that the high gain of the low noise amplifier makes the additional terms contribute very little to the total noise figure of the system. The results above show that the front end electronics add about 3.0 dB of noise to the system. Several techniques can be used to reduce the amount of noise added to the system, such as cooling the temperature of the components, or shortening the cable lengths by putting the electronics inside the tanks. These techniques were used in the anti-proton debuncher machine, and the noise figure was reduced to values less than 1 dB [4]. For this system, further reduction of the noise figure is not necessary.

The low noise amplifiers use 15 Volt, 1.5 Amp regulators for power. A PLC controller located upstairs in the MI-62 building controls the power to the regulators and the amplifiers. Care must also be taken as to the location of the regulators. A photodiode inside the regulator is very sensitive to excessive radiation, and can be easily damaged. The regulators are placed in positions in the tunnel where radiation is a minimum. Each amplifier has an ACNET database name, and the database names are listed in Table 1. The drawing number for the MI-62 tunnel electronics is #0880.00-LB-417036. A picture of the installed horizontal pickup tank is shown in fig. 5.

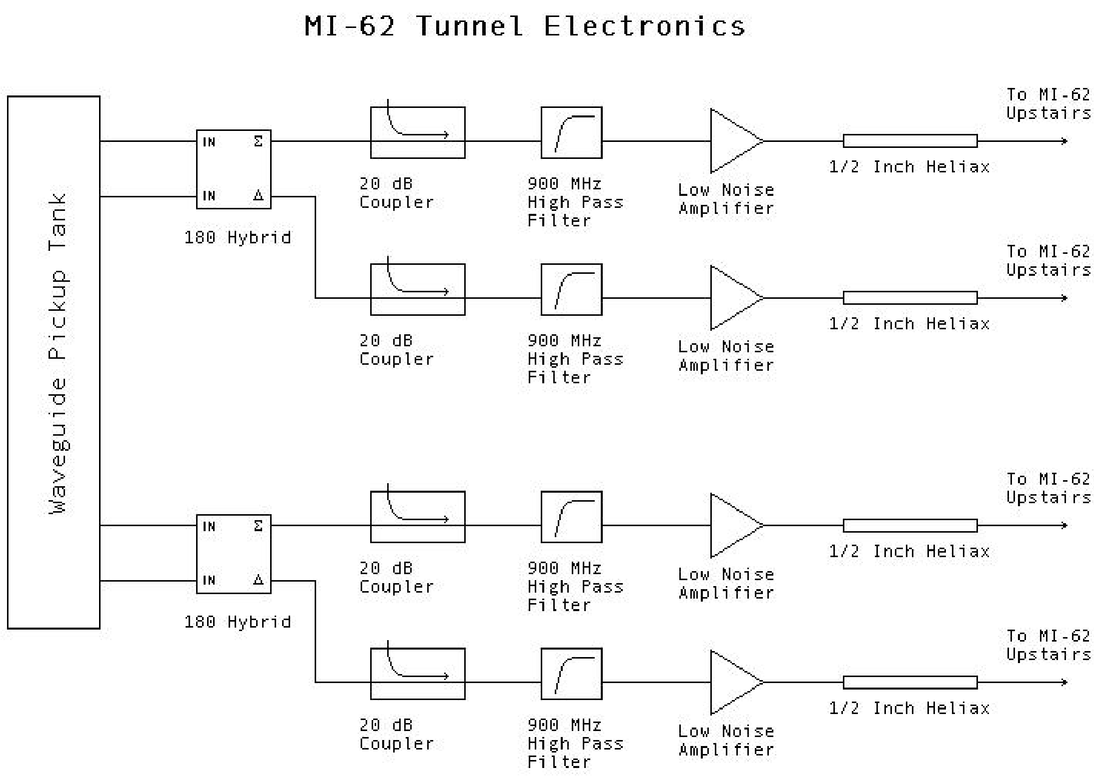


Fig. 4. Recycler MI-62 tunnel electronics

Horizontal Schottky Pickup - Recycler

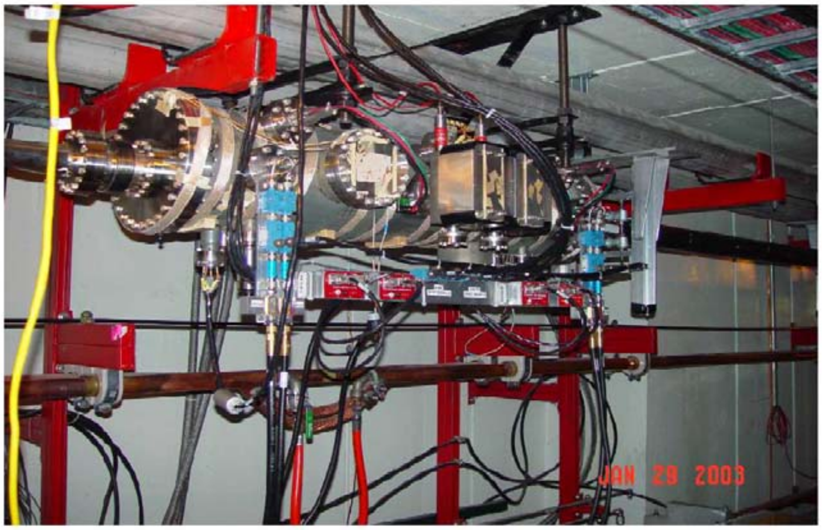


Fig. 5. Horizontal pickup tank

Table 1 Low Noise Amplifier ACNET database names

R:VPDLTA	vertical proton delta amplifier
R:VPSUM	vertical proton sum amplifier
R:VADLTA	vertical anti-proton delta amplifier
R:VASUM	vertical anti-proton sum amplifier
R:HPDLTA	horizontal proton delta amplifier
R:HPSUM	horizontal proton sum amplifier
R:HADLTA	horizontal anti-proton delta amplifier
R:HASUM	horizontal anti-proton sum amplifier

MI-62 Building Electronics

The electronics in the MI-62 building are located on the bottom half of rack MI62107. A diagram of the rack space is shown in fig. 6, and a photograph of the electronics installed in the rack space is shown in fig. 7. A block diagram of the electronics is shown in fig. 8. The first stage of the electronics is a Mini-Circuits ZHL-1042J amplifier that amplifies the signal from the tunnel. Next, the signal is down converted to a 2-8 MHz frequency bandwidth. Single sideband downconverters are used to down convert the signal. The reason for using single sideband downconverters is to preserve the symmetry of the signal, and to avoid overlapping of the betatron sideband signals from the "negative" frequency spectrum. This is important so that chromaticity measurements can be made, and also, the frequency dispersion of the momentum signal can been seen. A diagram of single sideband down conversion is shown in fig. 9. The upper sideband of the delta signal is down converted, and the lower sideband of the sum signal is down converted. The reason for down converting the lower sideband of the sum signal will be explained in the following section when the calibration signal is explained. The single sideband downconverters suppress the unwanted sidebands by about 22 dB.

The local oscillator signal for both the sum and delta down converters are also shown in fig. 8. The local oscillator signal is phase locked to the 52.8 MHz RF fanback from MI-60. The phase locked oscillators for the delta and the sum are tuned to the 33rd and 34th harmonic of the RF frequency, respectively. The delta LO frequency is 1.7427762 GHz, and the sum LO frequency is 1.7955876 GHz. The local oscillators are also used to generate sum and delta calibration signals. The calibration signals are injected into the system using the 20 dB couplers in the tunnel. They are used to test the overall system performance and as a reference to check if any of the components are malfunctioning.

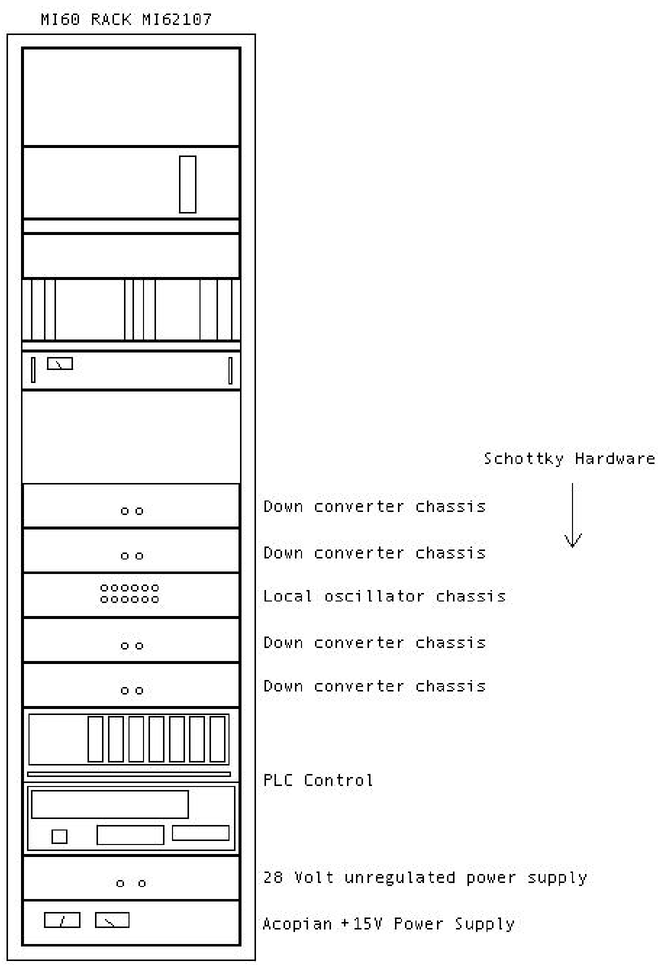


Fig. 6. MI-62 Building rack space

Fig. 7. Photograph of the electronics installed in MI-62.

Calibration Signals

The sum calibration signal is generated by mixing the delta frequency of 1.7427762 GHz with a 50 MHz oscillator. The resulting frequency components are 1.7427762 GHz plus/minus 50 MHz. The plus frequency is 1.7927762 GHz, which is 2.81 MHz below the local oscillator frequency of the sum signal. This means the calibration signal is on the lower sideband and can only be used if the sum signal down converts the lower sideband. This is the reason for down converting the lower sideband of the sum signal. The delta calibration signal operates on the same principle. The sum oscillator is mixed with the 50 MHz oscillator to generate a frequency component at 1.7455876 GHz, which is 2.81 MHz above the delta local oscillator frequency. This signal is in the upper sideband and can be down converted. A plot of the calibration signals is shown in fig. 10. Both sum and delta calibration signals will be seen at 2.81 MHz on the vector signal analyzer. The power levels of these calibration signals are recorded and plots of the signals are shown appendix A. The delta calibration signals have an additional 20 dB of attenuation before they are injected into the system. This is because the delta signal has an extra 20 dB of amplification down the signal chain. This should be used as a reference for any malfunctioning of the system. The calibration signals are turned ON or OFF using the ACNET database R:RFTEST.

After down conversion, a 50 MHz low pass filter is used to remove the high frequency components that are generated by the mixing. An amplifier is used to send the signals over to the MI-60 building. Details of the MI-60 electronics is shown in drawing #0880.00-LB-417035. The down converter chassis is detailed in drawing #0880.00-LB-417007, and the local oscillator chassis is detailed in drawing #0880-LB-417017.

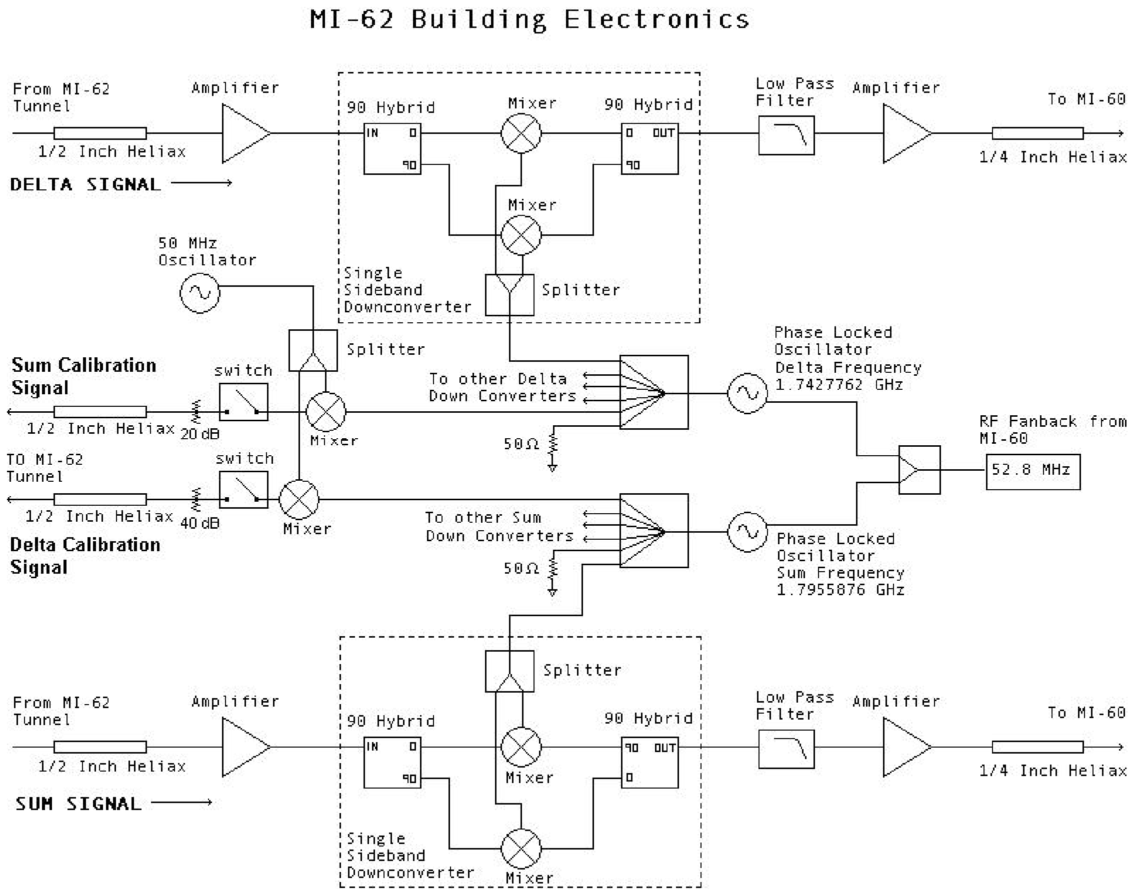


Fig. 8. Block diagram of MI-62 electronics

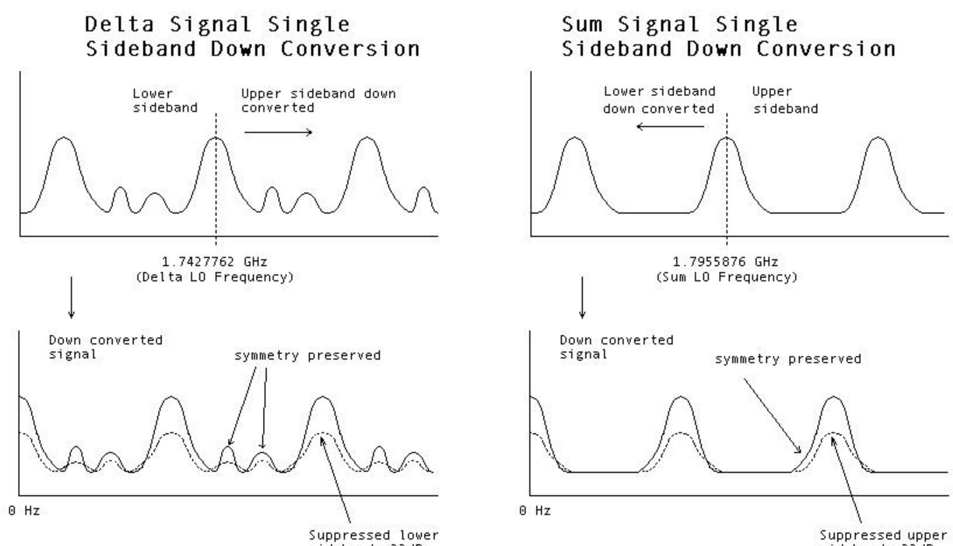
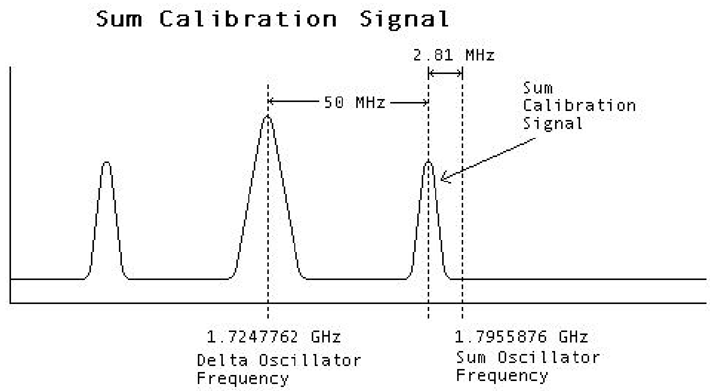


Fig. 9. Single sideband down conversion



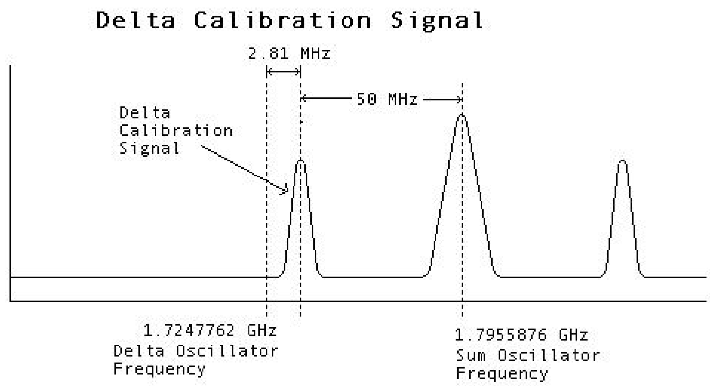


Fig. 10. Sum and Delta calibration signals

MI-60 Electronics

The signals are transferred from the MI-62 building to the MI-60 building using ¼ inch heliax cable. The electronics are installed in rack MI60027. A diagram of the rack configuration is shown in fig. 11. A photograph of the installed electronics is shown in fig. 12.

A schematic of the electronics is shown in fig. 13. First, a 10 MHz low pass filter is used to remove the total amount of schottky frequency components. This is done so that the following components do not compress and third order frequency components are reduced. The delta signal is amplified and split, and the signal is fed to the emittance monitor as shown in fig. 13. The emittance monitor measures the integrated power in one schottky sideband and produces an output in RMS volts. The output of the emittance monitor is fed into the MADC box located above rack MI60006. The RMS voltage output of the emittance monitor is converted into an emittance unit, and the data base names for the emittances are listed in Table 2. A more detailed discussion of the emmitance monitor is found in [5]. The sum signal is not amplified because it is a much larger signal.

Table 2 ACNET database names for emittance measurements

R:EMHP	Horizontal proton emittance
R:EMHA	Horizontal anti-proton emittance
R:EMVP	Vertical proton emittance
R:EMVA	Vertical anti-proton emittance

The delta signal and the sum signal are both fed into the gating circuitry. The gating circuitry splits the signal into three signals. Two of the signals are gated, and one signal is un-gated and used as a reference signal. The gated signals and the reference signals are multiplexed to the Vector Signal Anlayzer, located in the rack space shown in fig. 11. The reference signals are multiplexed to channel 1 of the VSA, and the gated signals are multiplexed into channel 2 of the VSA. The VSA is displayed on channel 24 of the main injector cable tv system. The multiplexed signals going to the VSA are controlled using ACNET pages R41 and R74. The reference signals are listed on R41, and the gated signals are listed on R74. An ACNET program on R37 displays the schottky signals along with tune and emittance measurements. The program allows the user to choose between gated and ungated protons or antiprotons. The program display is shown in fig. 14.

Gate Timing

The ON/OFF pulses that control the gates come from a VME crate located in rack MI60025. The timing of the gates is shown on a four channel oscilloscope located in MI-60. The scope is triggered by the MDAT pulse that also comes from the VME crate. Channel 1 of the scope shows gate #1, and channel 2 of the scope shows gate #2. The gates are hard wired into the oscilloscope. Channel 3 of the scope is an un-gated reference signal that is multiplexed in from ACNET page R41. Channel 4 of the scope is a gated signal that is multiplexed in from ACNET page R74. The scope display allows the user to look at the position of the two gates referenced to the actual schottky signal and the gated schottky signals. The scope can be viewed and controlled though the web address, http://rec-gate-scope.fnal.gov. The web page is shown in fig. 15. The scope can also be viewed on channel 25 of the main injector cable tv system. A more detailed discussion of the gating system and timing control is discussed in [6].

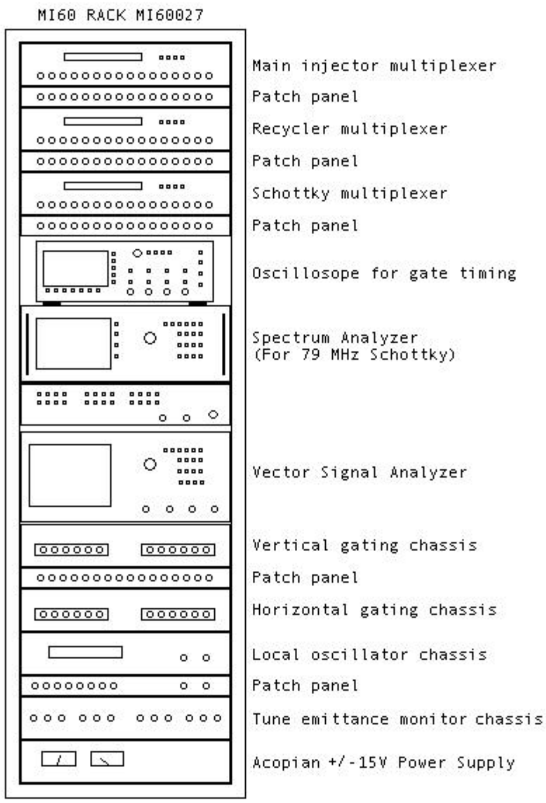


Fig. 11. MI-60 building rack space

Fig. 12. Photograph of the installed electronics.

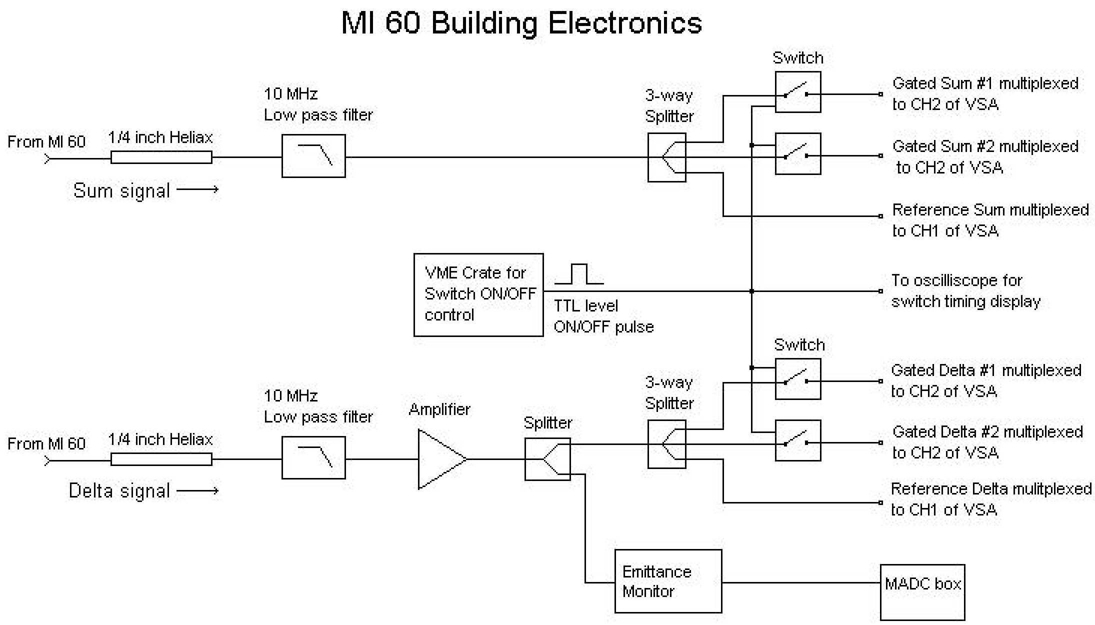


Fig. 13. MI-60 building electronics

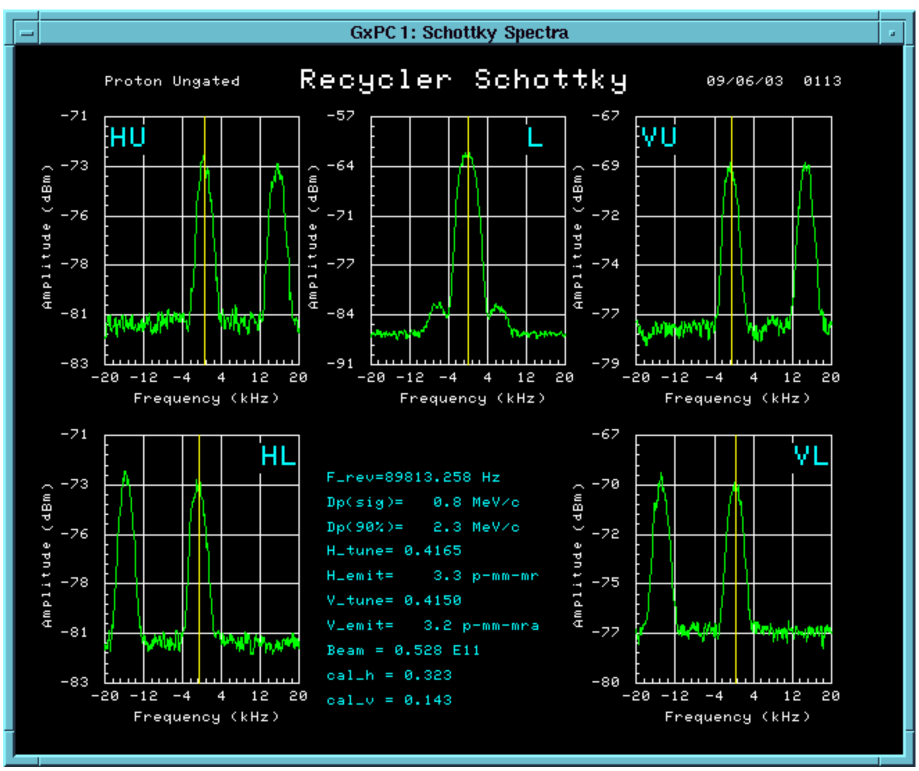


Fig. 14. Schottky display

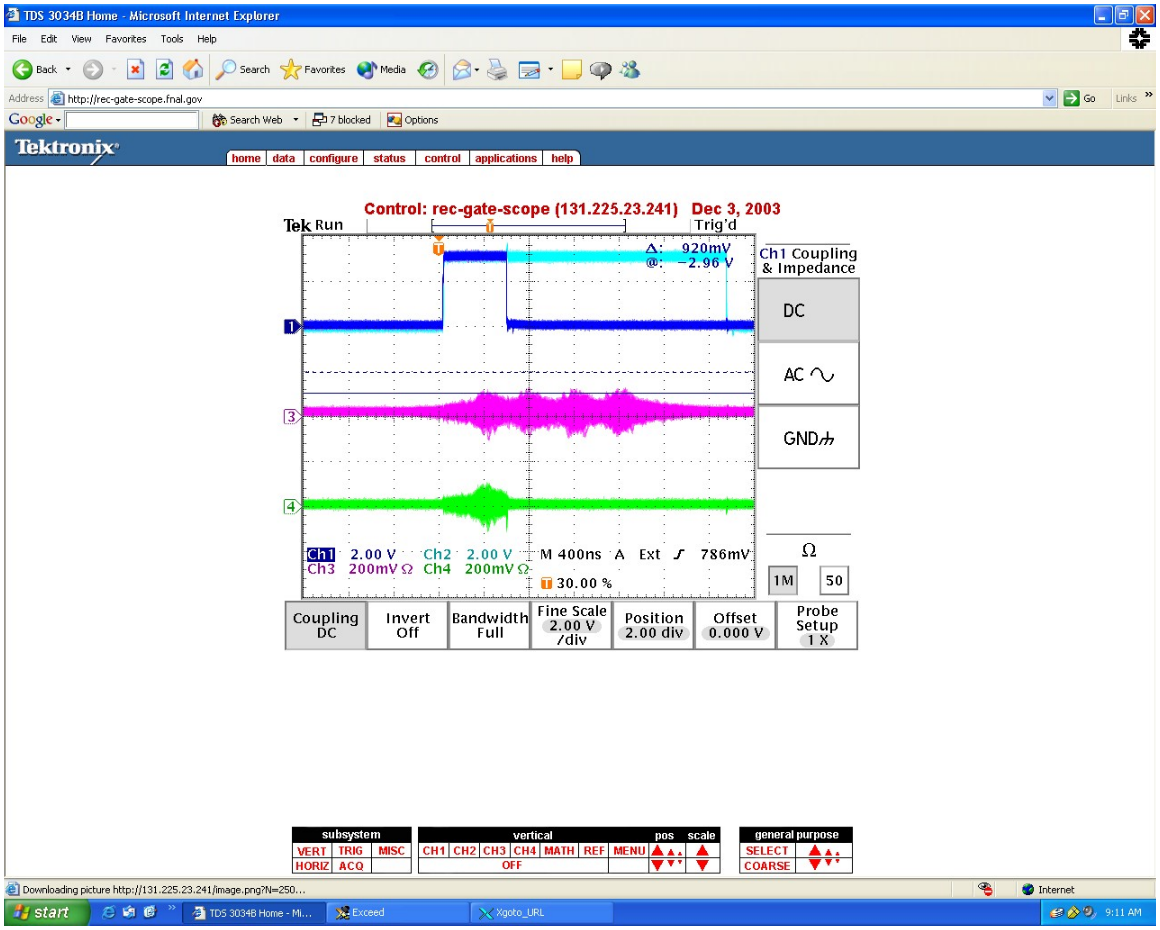
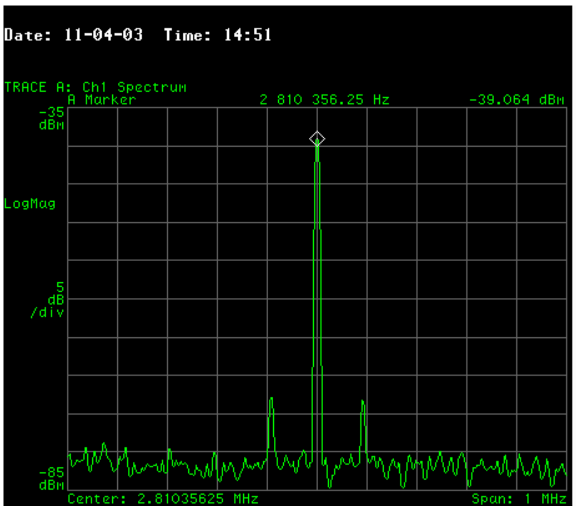
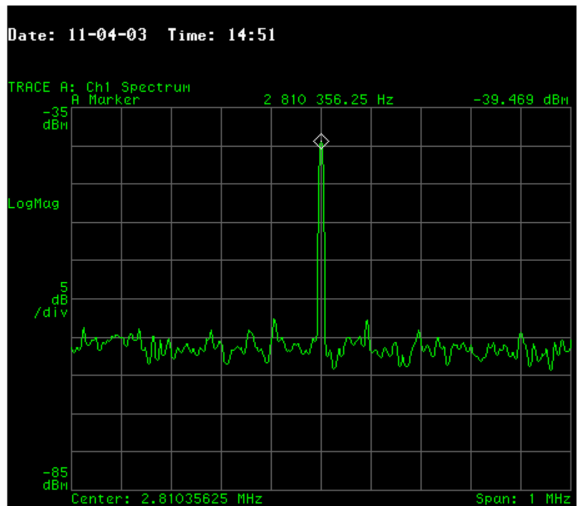


Fig. 15. Gate timing oscilloscope web page display

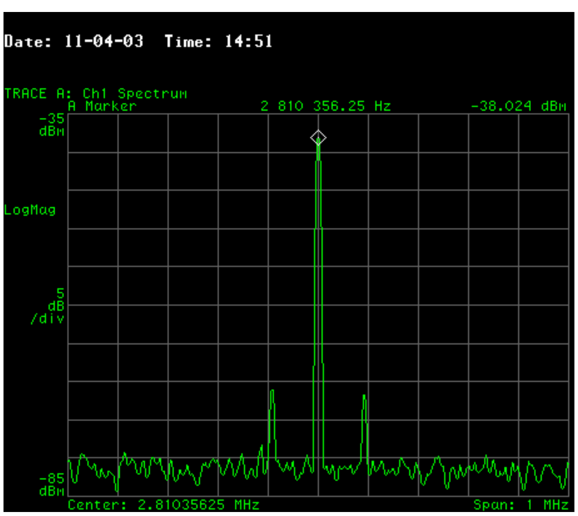
Appendix A
Calibration Parameters



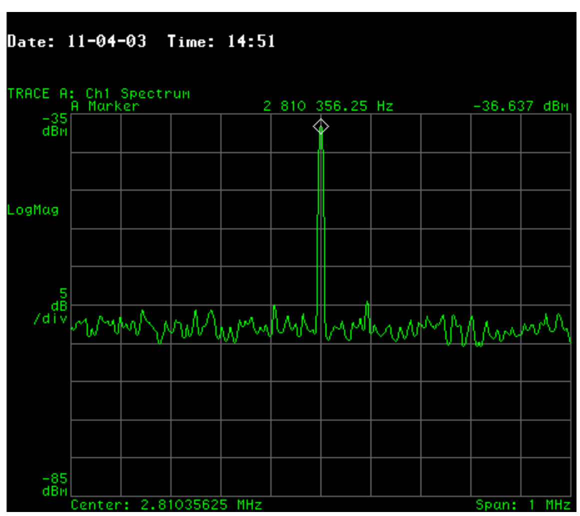
Horizontal Proton Sum



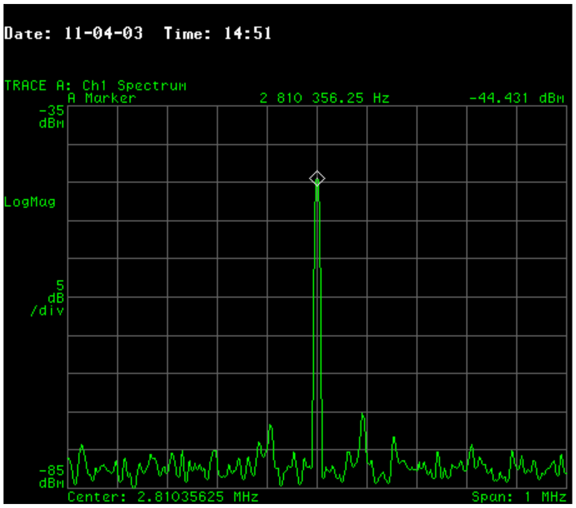
Horizontal Proton Delta



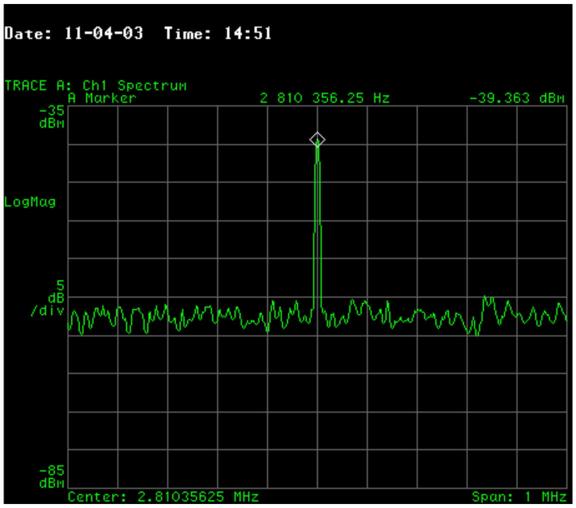
Horizontal Anti-proton Sum



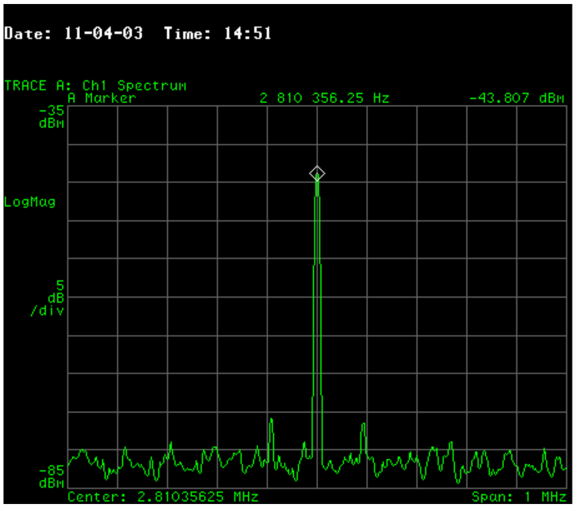
Horizontal Anti-proton Delta



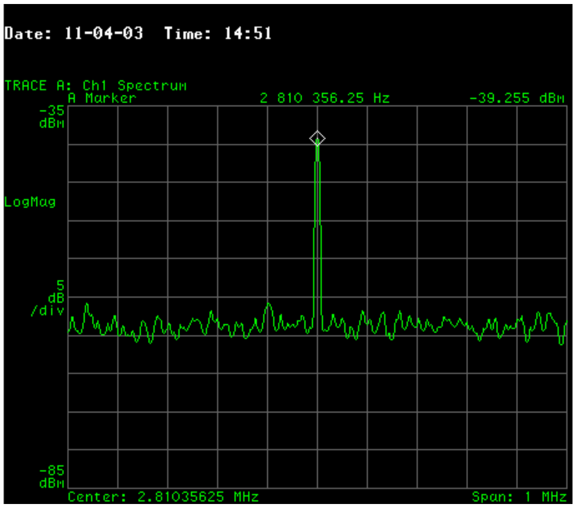
Vertical Proton Sum



Vertical Proton Delta



Vertical Anti-proton Sum



Vertical Anti-proton Delta

References

[1] D. Sun, “Design and RF Measurement Results of Schottky Pickup for Recycler and Tevatron,” Fermilab RF Department Note 49.

[2] D. Sun, “Design and Measurement Results of Microwave absorbers in Schottky Pickup for Recycler and Tevatron,” Fermilab RF Department Note 50.

[3] D. Sun, “Dimensions and Measurements of Waveguide-Coax Launchers in Schottky Pickup for Recycler and Tevatron,” Fermilab RF Department Note 51.

[4] R. Pasquinelli, “Noise Performance of the Debuncher Stochastic Cooling Systems,” Fermilab RF Department Note 10.

[5] E. Cullerton, R. Pasquinelli, “Dynamic Emittance Monitor for Recycler,” Fermilab RF Department Note 61.

[6] E. Cullerton. R. Pasquinelli, “Gating System for Recycler 1.75 GHz Schottky Detector,” Fermilab RF Department Note 62.